Development of a GIS-based Test Bed for Urban Models(都市モデル開発用GISテストベッドの構築)

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論文内容要旨

The present study has goal to develop a general test bed for urban model development and testing. Specifically, the objectives of this study are as follows. First, it is to develop a concrete idea of the test bed through the literature review of the existing urban models as well as the previous model testing projects. Second, it is to provide a data provision system for urban model development and testing. This is accomplished by developing a new spatial interpolation model and a data category conversions system. Third, it is to build a prototype test bed system with the real software and database where the general model interfaces are provided with the appropriate analysis tools. Fourth, it is to validate the test bed system in several applications, e.g., the policy analysis with a real urban model, the sensitivity and uncertainty tests, and the implication of the test results. The study has been developed based upon the conditions and requirements that are faced by the practical urban modelers in a scale of an urban area. Among the variety of urban modeling, this study emphasizes the land-use/transportation interaction models.

Literature review has shown the need to test and examine the existing operational model that is being used in the metropolitan planning organizations. It is found that the models being used are built with different objectives and scopes, which made them different in their natures, i.e., different models may give different responses to the same situation. It is also found that the models in the real applications are being used by the less-technical users. Due to the model's complexity, it is almost impossible for planners to test whether their model are used in an appropriate or optimal way. Similarly,

some of the previous model-testing projects are investigated. It is found that the existing works are focusing on the direct applications and directly comparing the results. Such limited view of testing models is primarily due to the lack of appropriate tool for the test, which generally requires very large work efforts. Therefore, this study has continued and improved the existing model testing works by employing the state-of-the-art computer technology with the innovative theoretical-based methodologies to develop, operate, and test the urban models more effectively.

As a methodological innovation, a nonstationarity spatial interpolation method is proposed for the development of a data provision system. In order to set the proposal within its statistical framework, a linear model characterized by a general variance-covariance matrix is described and used as the basis to derive a number of common interpolation methods. Three stationary interpolation methods are considered that, to different degrees, exploit the autocorrelation characteristic commonly found in spatial processes, but which fail to account for possible local variations in the behavior of the underlying process (i.e. nonstationarity). These are the multiple regression, regression with autocorrelated errors and Kriging models. A fourth method, namely geographically weighted regression, was also described as a tool for nonstationary interpolation, however noting that when the error terms of the underlying process are spatially autocorrelated, it fails to give optimal predictors. The power of the framework adopted for the proposed model is that it allows combining GWR's concept of locational heterogeneity for the estimation of spatially nonstationary parameters, the use of Kriging-style variogram functions to account for spatial autocorrelation, and the equations to obtain best linear unbiased parameters described by Goldberger (1962). The proposed method (named GWR-I) has special cases when some specific parameters are given, for example, $\rho = \gamma_o = 0$ results in ordinary least square model, or $\gamma_o = 0$ results in Kriging model. In the other word, GWR-I model successfully uses nonstationary, location-specific parameters while exploiting spatial autocorrelation in order to obtain best linear unbiased predictors.

Two numerical examples are presented which are the typical problems in the area of urban modeling, i.e., interpolation of population and household density respectively. The similar results show that use of the nonstationary interpolation method proposed in this study may lead to small but potentially useful performance gains. Three measures of goodness-of-fit were used to examine the

performance of the different models, namely Akaike's Information Criterion, a cross-validation score and the sum of errors. Similarly, a confidence interval of the prediction is calculated. The narrower confidence interval indicates that the prediction by GWR-I model is very accurate. A superior performance resulting from incorporating nonstationarity as part of the interpolation process can be obtained, therefore the method provides another option to estimate the necessary data in the urban modeling. It must be noted, however, that in many cases how well a model performs depends to a large degree on the characteristics of the data and the variables used, and accordingly no method can be thought of as being universally superior. This reconfirms the contributions of the present study, which provides methodological tools for testing the urban models. The flexibility of GWR-I will allow it to perform reasonably well in many situations of various urban models, as compared to the use of models built upon more restrictive assumptions, or sometimes ad hoc. That is, the proposed model is proved to be an alternative method for spatial interpolation when the nonstationarity and spatial autocorrelation are coincidentally the issues for the analysis. It is expected to help improve the performance of urban model by providing more accurate data that is required by the model.

The next part of this study is the development a real test bed system. It is an operational innovation that a general design is presented with the latest computer technology employed, e.g., the standard database connectivity, the component object model, etc. Three main points are emphasized in the system development: GIS-based database, system flexibility, and user friendliness. The design specification of the test bed has shown several improvements in many aspects. The system integrity is improved because there is one unique database rather than many text files; the live connection to the central database from everywhere within the system is done by ODBC. The system provides flexibility in the operation and development with its modular structure and the COM protocol. For example, the urban model can be implemented and tested in the test bed by only linking the model with a model-specific interface module where the original system need not to be changed. Similarly, the different computing tools can be used and replaced at any time. The different levels of database and GIS packages can be upgraded depending on complexity of the study. Next, the system reliability is high because the software packages used are generally known and already in use. Finally, the system also allows working in a network environment. Because the database is referred through DSN, the system

can work efficiently in the network-computing environment. This is largely required in most of the large planning organizations where different models are carried out in different work sections. Lastly, the user friendliness is emphasized to bridge the gap between model developer and model users with sometimes less-technical skill. Therefore, the design specification of the test bed has overcome the disadvantages and limitations of the previous model testing works.

With the design specification described above, a prototype system of the test bed is built for Sapporo Metropolitan area of Japan. The system is equipped with many useful tools aiding the urban model development and testing. The program is fully user-oriented in the sense that all operations can be done within the graphical menus. Various data usually needed for urban model development is provided by fully utilizing the functionality of Geographic Information System (GIS). Three main useful tools are provided: the spatial interpolation tool, the sensitivity analysis tool, and the category data conversion tool. The operations of these modules are simple with the graphical user interface. In addition, an automated data interface is provided to facilitate the connection of input/output of the urban models. The program is general and flexible so that it can be implemented in the other area easily. The general interface module allows the existing urban models be implemented and tested easily with less effort. In the other word, if this system is installed in a planning organization, the planners can check the validity of their models easily. Moreover, installation of the software is simple so that the software can be distributed over the internet and user can implement it easily. Therefore it can be said here that the computer technology is utilized in order to improve the efficiency and performance of urban model.

Lastly, two applications of the prototype test bed system developed are presented. In the first application, the Sapporo test bed is used to develop of the TRANUS model for Sapporo metropolitan area. Since TRANUS is a general model framework that must be designed specifically for each implementation case, the TRANUS model of Sapporo is a result of repetitive designs and calibrations in order that it could represent the behavior and characteristic of Sapporo metropolitan satisfactorily. This development of Sapporo model is the first application of the TRANUS framework for the Asian cities, which are obviously different from American cities or the Latin cities where the model was originally developed. Its representation of the economic and land sectors is distinguished from the other models of

TRANUS elsewhere. The developed model was used in a meaningful and hard-to-find way, which contributes to the practice of the travel demand analysis. In words, it is shown with the empirical results that land-use modeling must be incorporated in the travel demand forecasting procedure because the effect of transportation to land-use is proved to be so large that should not be neglected. This application takes advantage of the Sapporo test bed in many ways such as the use of the comprehensive set of data, the reduction in the manual operations, etc. Next, as the second application of the Sapporo test bed, the analysis of error and uncertainty of the urban model is presented. It is an efficient simulation tool to determine the dominant inputs and parameters that mainly cause the uncertainty in the final model forecasts. Such uncertainty is resulted by the accumulated uncertainty through quasi-dynamic structure of the general urban model. Therefore, in order to cope with this uncertainty problem, a heuristic approach to determine a desirable time step for quasi-dynamic model is proposed. The desirable time step is said to be a trade-off between uncertainty and accuracy of the final model results. The numerical simulation has suggested using 3.3 years as time step for the modeling. However, this number might not be appropriate from the viewpoint of the practical modeling due to data availability, data collections, etc. It is then considered acceptable to 5 years as the model time step because the results of using 3.3-year and 5-year time-steps are not very different. Therefore this study has proved that the time step of 5 years (conventionally used in the most cross-section model) is still valid from the considerations of uncertainty and accuracy, based on the numerical results of the simulation. Although the work presented in this study is a simplified analysis, it is very effort and time consuming indeed. Therefore many advantages of Sapporo test bed are realized. For example, the sensitivity analysis of model output at zone level does not exist previously simply because the amount of work was too large to be handled without this kind of system, which is provided with the appropriate tools. The study has concluded with some recommendations for further researches such as to develop the test bed system by the platform-independent language such as Java, to perform a full set of simulation for the uncertainty analysis, etc.

論文審査結果の要旨

都市圏の総合計画や交通計画策定における各種政策手段の効果影響分析を目的に、世界各都市圏で都市シミュレーションモデルが構築されている。しかし、それらのモデルは利用可能なデータのもとで個別に開発されていることからパフォーマンスの相互比較等が困難であるとか、新規にモデルを構築する際には標準的なデータが存在しないといった問題が存在する。そこで、本究においては、都市モデルの開発およびその性能試験のための、汎用的なデータ提供および各種試験システムから構成されるテストベッドを構築することにより、都市モデルの新規開発や既存モデルの改良に資することを目的としている。本論文はこの研究をまとめたものであり、全文７章よりなる。

第１章は序論であり、本研究の背景および目的を述べている。

第２章では既存の関連研究について整理し、本研究の基礎としている。

第３章では、空間データ処理に関する方法論的な開発として、空間的非定常性を考慮した空間補間法を提案している。これは、空間的重み付け回帰（GWR）モデルで用いられる位置に依存する空間的非定常パラメータの概念と、空間自己相関係数モデルである Kriging 法のコバリオグラム関数の考え方とを統合させた空間補間モデルである。この方法をゾーン別人口の補間推定に用いることにより、通常の回帰モデルや GWR モデル、Kriging 法に比べ十分に有用であることが確認されている。

第 4 章では、コンピューターシステムの操作性向上に関わる開発として、ODBC(Open Database Connectivity)標準や COM(Component Objective Model)プロトコル等を駆使して、テストベッドの標準デザインを提案している。この設計により、多様なアプリケーションの接続性と操作性の高さを実現している。また、札幌都市圏において実際のデータを用いてテストベッドのプロトタイプを構築している。このシステムでは、地理情報システム（GIS）の機能をフル活用して各種の都市情報を蓄積する一方で、第３章で述べた空間補間法、各種の相関データから不足主題データを推定する方法、そして、各種都市モデルとのインターフェース等を整備している。

第５章では、世界的に実績を持つ都市モデルの一つである TRANUS を検討対象モデルとして、このテストベッド上で構築している。その一つの適用事例として、交通計画における土地利用モデル導入効果について検討している。従来の一般的な交通需要予測においては、将来土地利用を与件として分析を行っている。本適用においては、土地利用モデルを用いて土地利用変化を内生化することによる予測の有用性について、従来型の予測との比較を通して明解に示している。

第６章では、テストベッドの機能を用いて、不足データの推計を行った上で、土地利用交通統合モデルで多く用いられている準動学的予測方法に関して、時間単位の長さがもたらす影響を、予測値の変動係数と決定係数を用いて評価している。この結果、形式的には 3.3 年間隔での予測が最も望ましいといえるが、実用上は、一般に慣例として行われている５年間隔の予測に十分な妥当性があることを示した。

第７章は結論と今後の課題についてまとめている。

以上要するに本論文は、従来の都市モデル開発における最大の問題点であるデータ提供機能を標準的に整備することにより、都市モデル開発の効率化と、それらのパフォーマンスの客観的な相互比較を可能とするシステムを開発したものであり、今後の都市モデル開発に対して大きく貢献することが期待される。

よって、本論文は博士（工学）の学位論文として合格と認める。